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# RESEARCH MEMORANDUM

A FUEL-DISTRIBUTION CONTROL FOR CONTINUOUS-FLOW  
MANIFOLD INJECTION ON RECIPROCATING ENGINES

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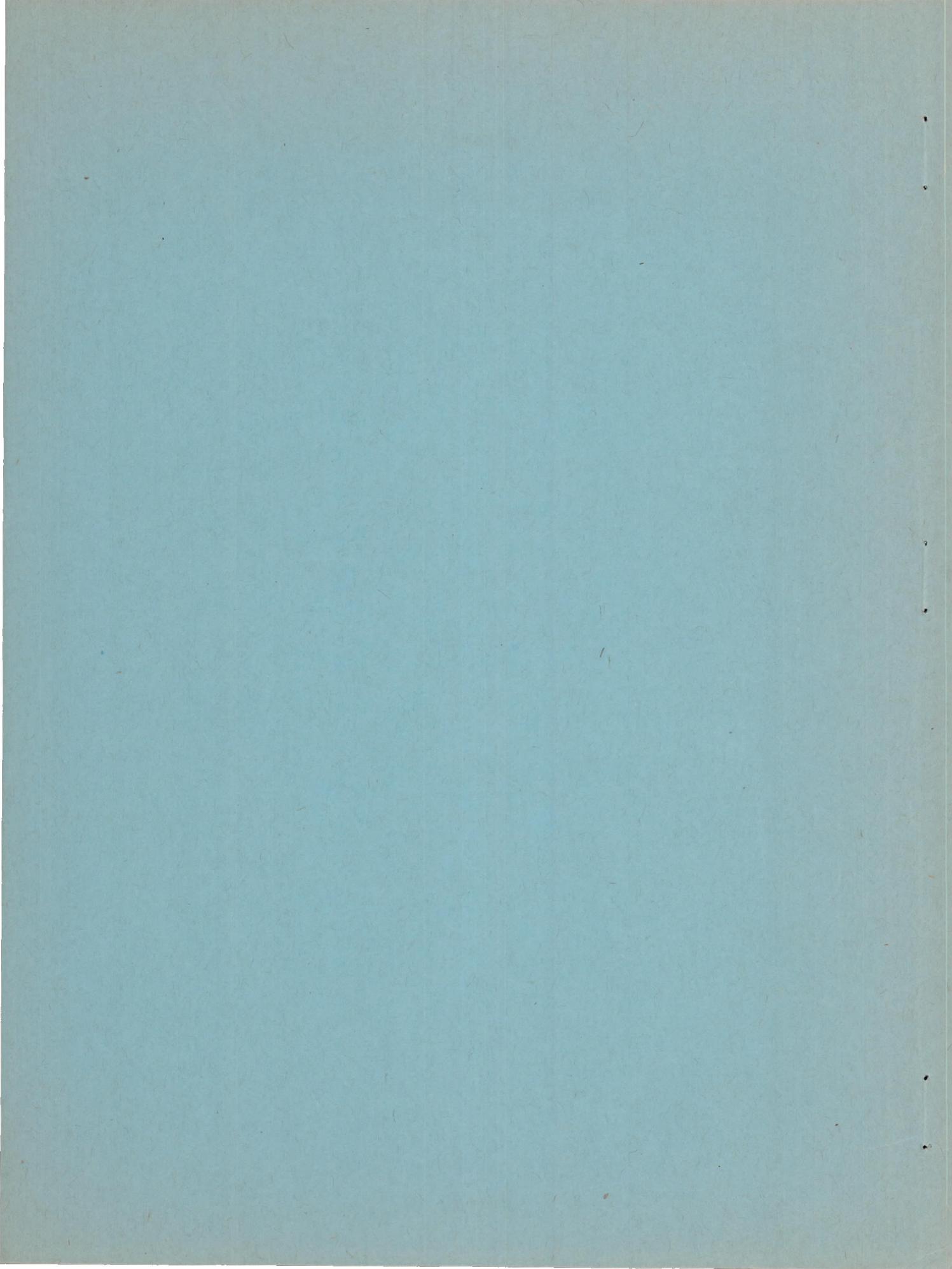
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RESEARCH MEMORANDUMA FUEL-DISTRIBUTION CONTROL FOR CONTINUOUS-FLOW  
MANIFOLD INJECTION ON RECIPROCATING ENGINES

By Harold Gold and David M. Straight

## SUMMARY

A fuel-distribution control for continuous-flow manifold injection on reciprocating engines is described. A method of installation of the control on an engine is suggested. The device controlled the flow to four spring-loaded nozzles within 2 percent of perfect distribution over a wide range of fuel-flow rates and the distribution was practically unaffected by uneven discharge-nozzle pressures.

## INTRODUCTION

In the course of an investigation at the NACA Cleveland laboratory of the distribution of fuel to the various nozzles of gas-turbine engines, a method was devised for accurately dividing the fuel flow into a number of equal streams. This method has proved to be so simple and accurate that its application as a means for controlling fuel distribution in continuous-flow manifold-injection systems for reciprocating engines appears possible.

In previous attempts to employ the continuous-flow manifold-injection system, fuel manifolds have been used to feed the individual discharge nozzles. If the fuel manifold is large and symmetrical, the effect of fluid friction is negligible and the fuel reaches all the discharge nozzles at the same static pressure. If all the nozzles have the same area and equal coefficients at all flow rates, the rate of flow through the discharge nozzle will at all times be equal. The complexity imposed on the nozzle by the need for a well-atomized discharge, however, introduces dimensional and frictional effects that make the equalizing of fuel-flow rates through the nozzles over a wide range of fuel flows extremely difficult. With the relatively low pressures used with current pressure-type fuel-metering controls for reciprocating engines, differences in nozzle elevations and inertia forces markedly affect the fuel distribution. In addition, with all

fuel pressures, the malfunctioning of one nozzle can greatly disturb fuel-flow rates to the other nozzles. By means of the distribution-control method described, these effects can be entirely overcome.

The principle of operation of the fuel-distribution-control method, a suggested method of engine installation, a description of a model built for initial bench checking, and the results of the bench check are presented.

#### PRINCIPLE OF OPERATION

Control method. - If matched metering jets were placed upstream of the discharge nozzles in each branch of a fuel manifold, the static pressure of the fuel on the upstream side of the jets would be equal in each branch but the downstream static pressure would be affected by the discharge nozzle and the fuel distribution would not be improved. If, however, automatic valves were placed between the metering jets and the discharge nozzles to maintain equal static pressures on the downstream side of the metering jets in each branch, the distribution would be controlled by the metering jets and would be unaffected by the discharge nozzles. Such a system, schematically shown in figure 1, is the basis of the fuel-distribution control developed during this investigation.

Control mechanism. - A schematic diagram of the fuel-distribution control is presented in figure 2. Fuel is delivered to this control under pressure from a pressure-type metering control (not shown). The fuel flows through the inlet and fills the manifold passage. From the manifold passage the fuel flows into the individual manifold branches and through the branch metering jets and the downstream pressure-regulating valves to the individual branch discharge nozzles. Fuel also flows from the manifold passage into the pilot branch, through the pilot metering jet and the pilot regulator jet, to the pilot discharge nozzle.

By means of the pressure-equalizing passage, the static pressures in the individual chambers A are maintained equal. The control diaphragms that separate chambers A and B position the downstream pressure-regulating valves until the pressures in chambers B are equal to the pressures in chambers A.

If the branch discharge-nozzle pressures are equal to the pilot discharge-nozzle pressure, the static-pressure drop across each of the downstream pressure-regulating valves will be equal to the static-pressure drop across the pilot regulator jet. The open area of the

valves will then be proportional to the area of the pilot regulator jet and this area will remain fixed at all fuel-flow rates. If any one branch discharge-nozzle pressure should rise above the pilot discharge-nozzle pressure, the downstream pressure-regulating valve in the branch supplying that nozzle would have a reduced static-pressure drop and would move to a position of larger opening. If any one branch discharge-nozzle pressure should fall below the pilot discharge-nozzle pressure, the reverse would occur. In either case the static-pressure drop across the metering jet remains equal to the drop across the pilot metering jet and the fuel distribution is undisturbed.

The flow from the pilot branch can discharge into the engine intake manifold supplying one cylinder. Because of the dependence of the entire system, however, on the flow in the pilot branch, it may be advisable to return the pilot flow to the fuel tank as indicated in figure 2.

#### EXPERIMENTAL MODEL, APPARATUS, AND PROCEDURE

Description of experimental model. - A photograph of the experimental model of the four-branch fuel-distribution control used in the bench runs is shown in figure 3. The control diaphragms are mounted on four faces of a cube. In operation, the control is so mounted that the control diaphragms are each in a vertical plane, which eliminates the effect of the valve-plug weight on the pressure in chamber B. Other arrangements can be used but the weight of the plugs must always be made to act in the same direction on all the valves. The pilot metering and regulator jets were in a separate housing, which is not shown in figure 3.

Matching of metering jets. - The metering jets used in the experimental model were drilled and then placed in a Navy-type orifice comparator. (See reference 1.) While in the comparator, the four jets were matched by polishing with crocus cloth. After the jets were matched on the comparator, a flow check was made with naphtha. The results of the flow check (fig. 4) show that the four jets which were matched in the comparator give nearly identical flows over a wide range of metering heads.

Bench apparatus. - The apparatus used with the experimental model of the fuel-distribution control is shown schematically in figure 5 and photographically in figure 6. Total-fuel-flow rate to the distribution control was measured with a rotameter having a range of 200 to 2000 pounds per hour. The fuel flowing through each branch passed through a rotameter having a range of 40 to 200 pounds per hour. Above

a total fuel flow of 800 pounds per hour, therefore, only the total-flow rotameter could be used. From the branch rotameters the fuel was discharged through four diaphragm-operated, spring-loaded nozzles. One of the four nozzles was vented to a variable-pressure air line in order that its discharge pressure could be varied. A well-type mercury manometer was used to measure the discharge-nozzle pressure. The four branch rotameters were calibrated in series after installation on the bench apparatus. The calibration was recorded by plotting the float position of each rotameter in millimeters against the fuel-flow rate in pounds per hour as indicated by one of the four rotameters. The fuel flow through the pilot branch was measured with a rotameter having a range of 3 to 25 pounds per hour.

The pressure drop across each of the metering jets was measured with a 100-inch naphtha manometer. Each chamber B was connected to one tube of a bank of four tubes that was arranged as shown in figure 5. The differences in the level of the fuel in the four tubes indicated the differences in static pressure in the four chambers B and thereby the accuracy with which the downstream pressure-regulating valves were functioning.

The fuel was naphtha having a specific gravity of 0.74 at a temperature of 70° F.

Engine installation. - A suggested method of installation of the distribution control on a reciprocating engine is shown in figure 7. The metering control must be of the pressure type.

#### RESULTS AND DISCUSSION

Discharge-nozzle calibration. - The discharge nozzles that were used in the bench runs on the experimental model were first operated on a manifold to determine the ability of the nozzles to distribute the fuel equally. The results of this calibration, which are shown in figure 8, indicate a maximum deviation of 30 percent from perfect distribution.

Performance of experimental model. - The bench performance of the experimental model of the fuel-distribution control is shown in figure 9. In the range of total fuel flow from 180 to 300 pounds per hour, the deviation of any branch flow from perfect distribution was less than 2 percent. Above a total fuel flow of 300 pounds per hour, the deviation was less than 1 percent. Although branch-rotameter ranges limited the maximum recorded branch fuel flow, use of the total-flow rotameter alone extended the total-fuel-flow range to the

limit of 1260 pounds per hour imposed by the bench apparatus. Comparison of the pressures in chambers B indicated that the same accuracy of control was maintained over this additional range. Comparison of the results shown in figures 8 and 9 clearly indicates the marked improvement that can be obtained with this type of automatic fuel-distribution control.

In order to demonstrate the ability of the experimental model to compensate for uneven nozzle pressures, the discharge pressure of one of the four nozzles was varied from 3 to 13.8 inches of mercury gage while the three others were kept at an approximately constant pressure of 11 inches of mercury gage. The flow through the control was kept constant at 370 pounds per hour. The results of this run, which are given in figure 10, show that the branch-fuel-flow rate remained constant within 3 percent over the entire range of nozzle pressures from 3 to 13.3 inches of mercury gage. Above a pressure of 13.3 inches of mercury gage, the downstream pressure-regulating valve in that branch began to lose control. The fuel-distribution control can be made to compensate for a much wider range of uneven nozzle pressures at any pressure level by altering the dimensions of the downstream pressure-regulating valve and the size of the pilot regulator jet.

#### SUMMARY OF RESULTS

From a bench investigation of an experimental model of a fuel-distribution control for a reciprocating engine, the following results were obtained:

1. The experimental model controlled the fuel-flow rate to four unmatched discharge nozzles within  $\pm 2$  percent of perfect distribution at a total-flow rate of 180 to 1260 pounds per hour.

2. The experimental model maintained the fuel-flow rate through a discharge nozzle within 3 percent of a constant value while the discharge-nozzle pressure was varied from 3 to 13.3 inches of mercury gage.

Flight Propulsion Research Laboratory,  
National Advisory Committee for Aeronautics,  
Cleveland, Ohio.

REFERENCE

1. Anon.: Instruction Manual D-3217 for Operation of Orifice Comparator-Navy Type Model III, Bureau of Aeronautics. Instruction Manual D-3217, The Meriam Instr. Co. (Cleveland), Jan. 10, 1944.

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Fig. 1

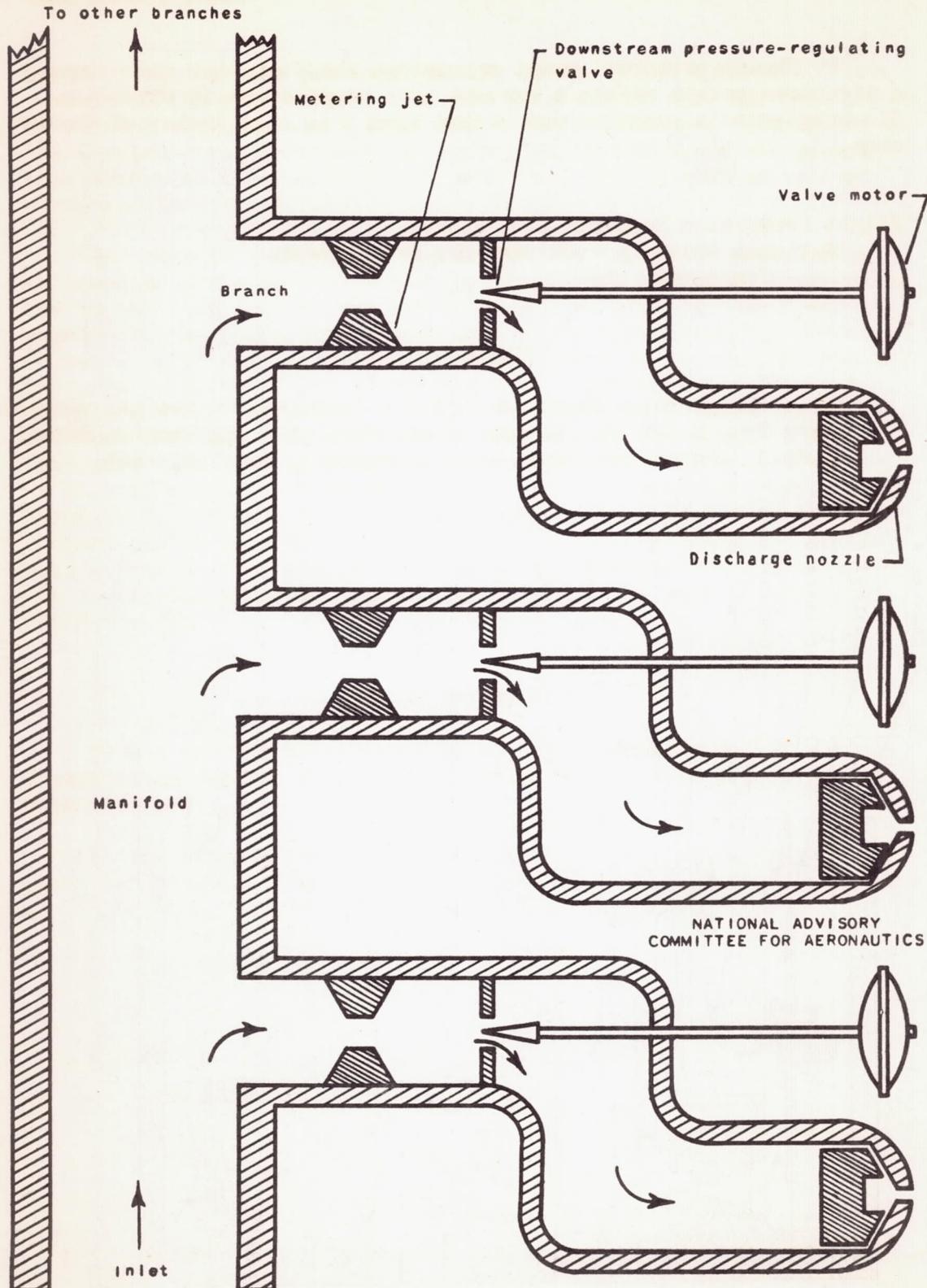


Figure 1. - Schematic diagram of control elements in apparatus for maintaining equal fuel distribution to unmatched nozzles.

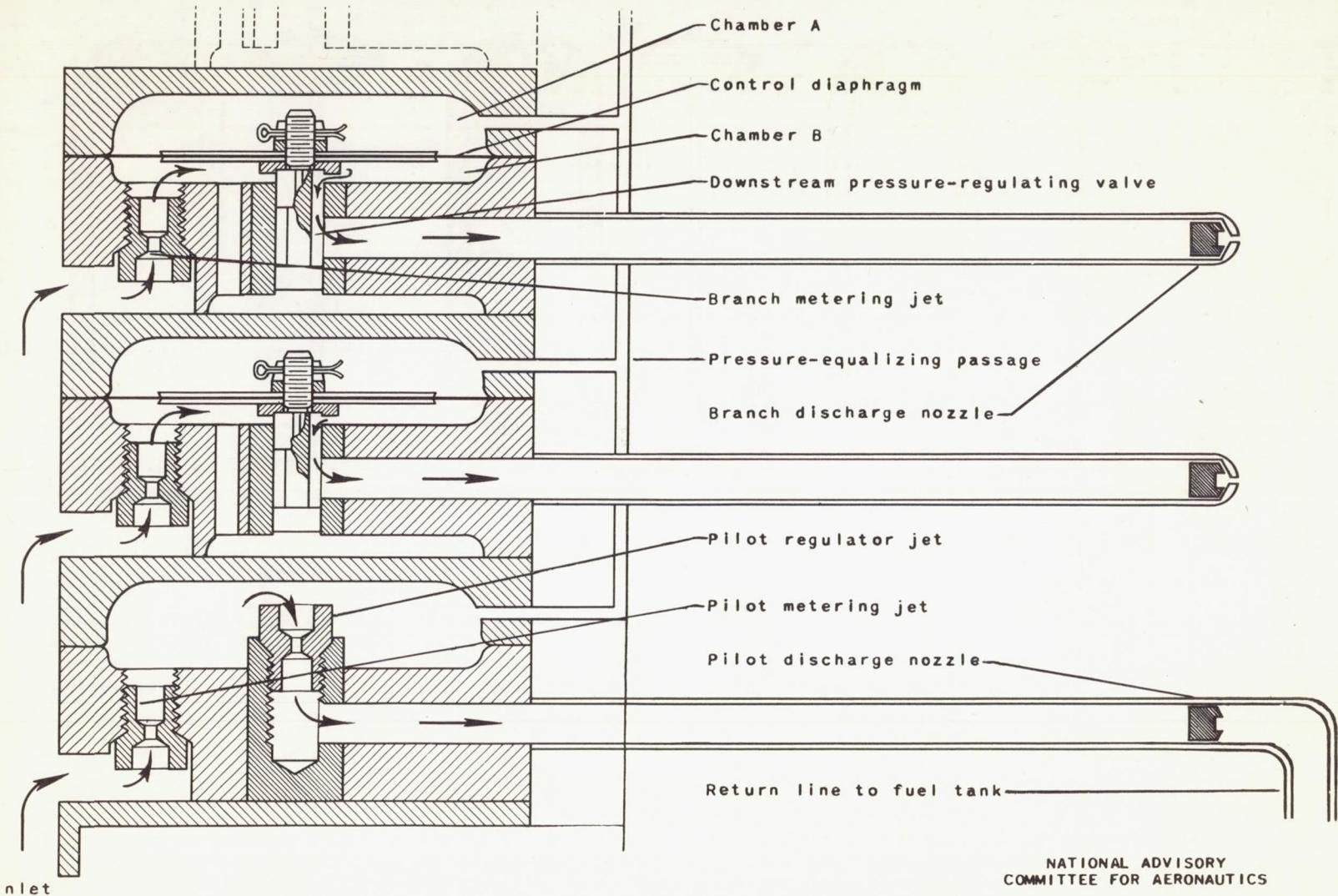


Figure 2. — Schematic diagram of fuel-distribution control for continuous-flow manifold injection.

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Fig. 3

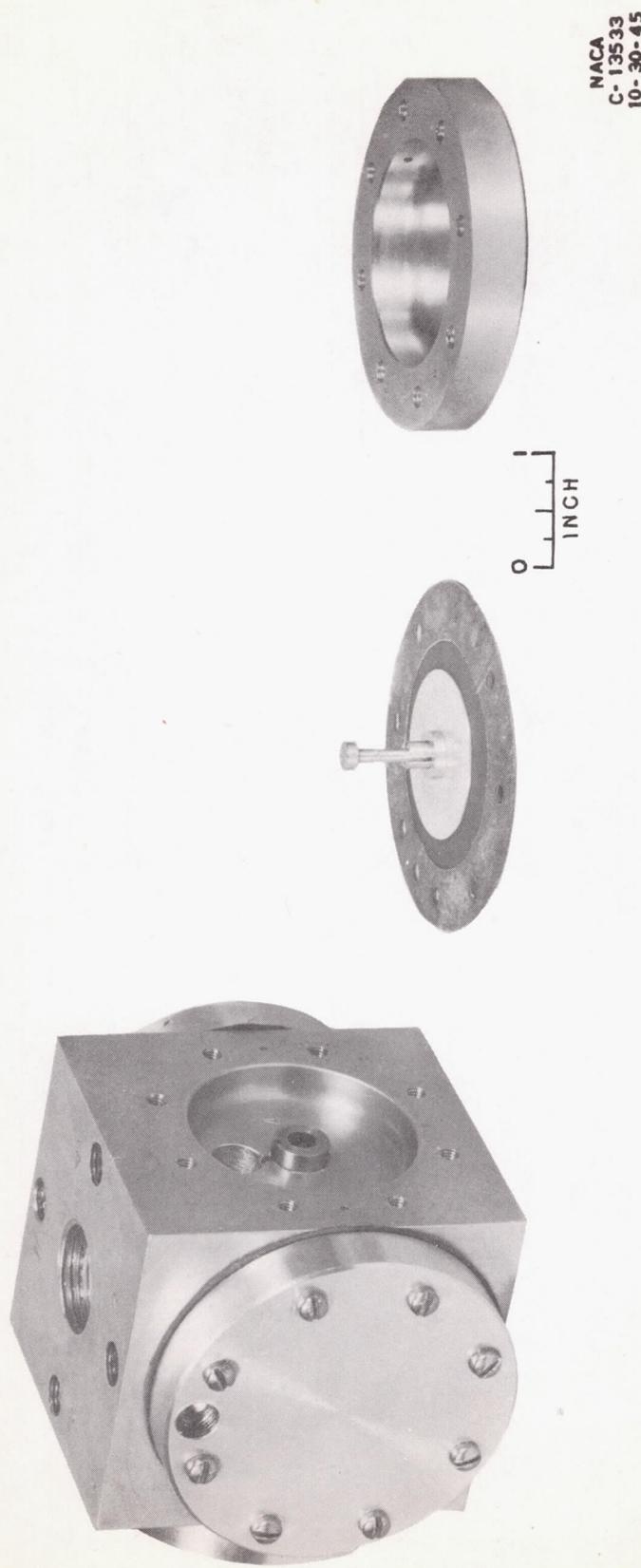
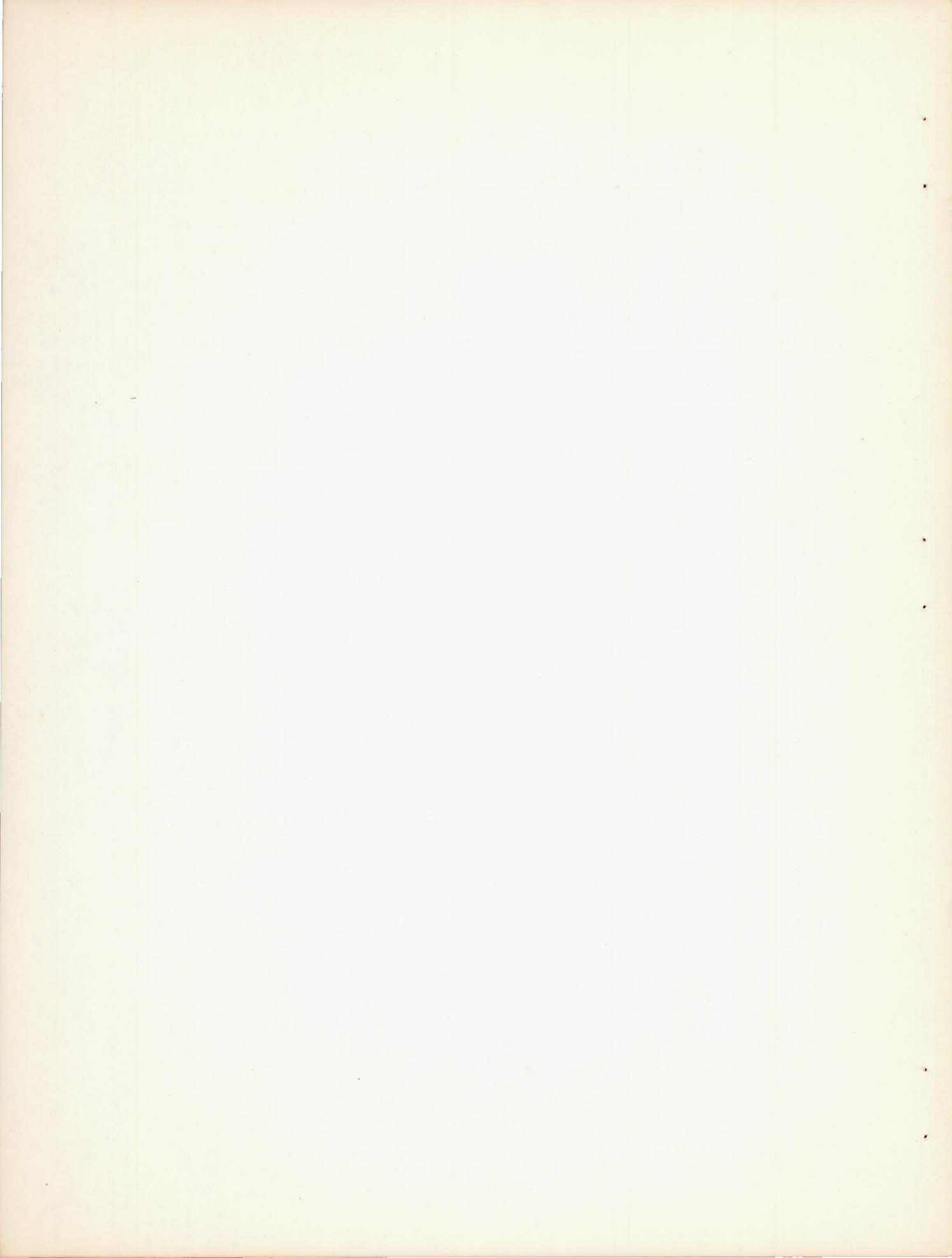


Figure 3. - Experimental model of fuel-distribution control.



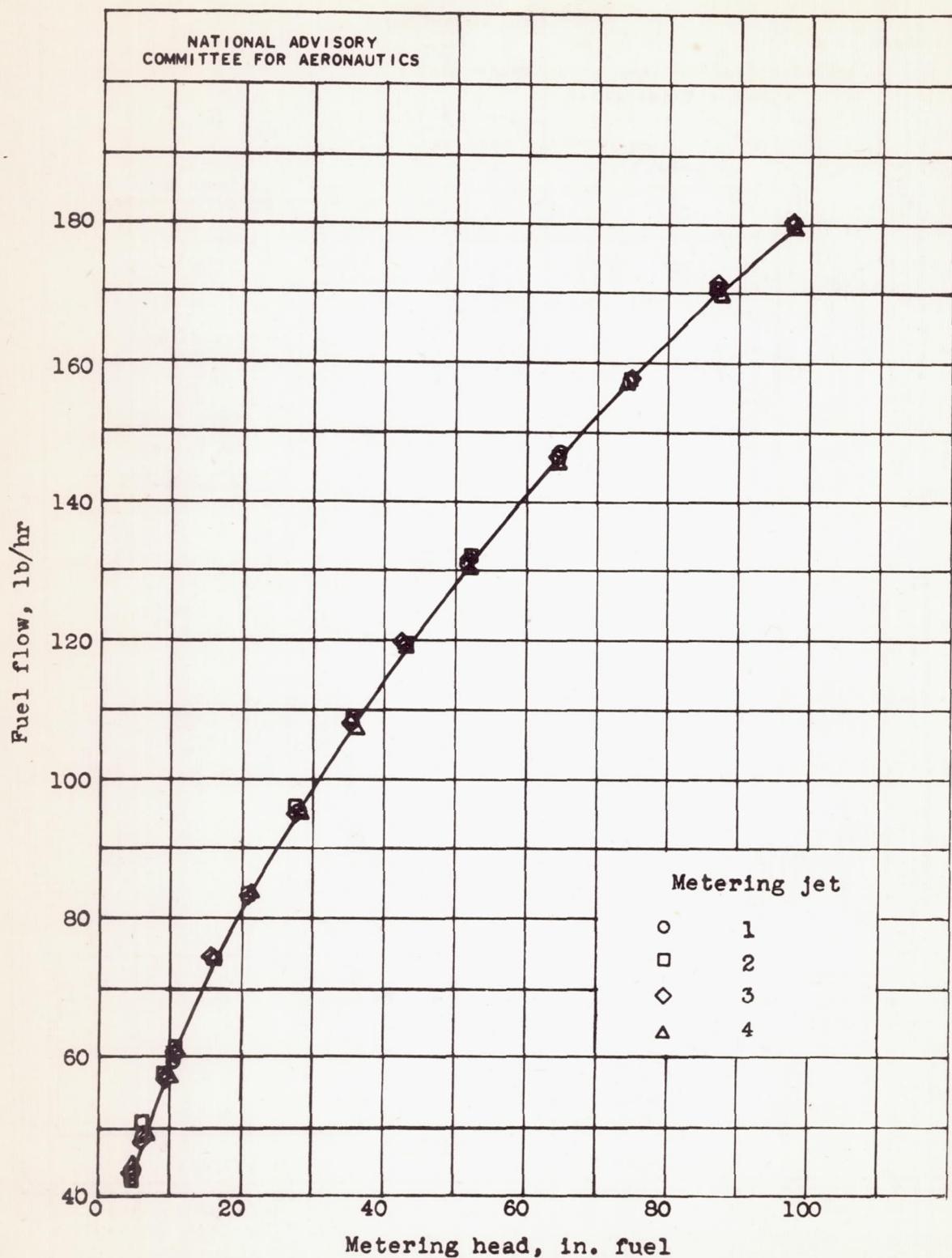
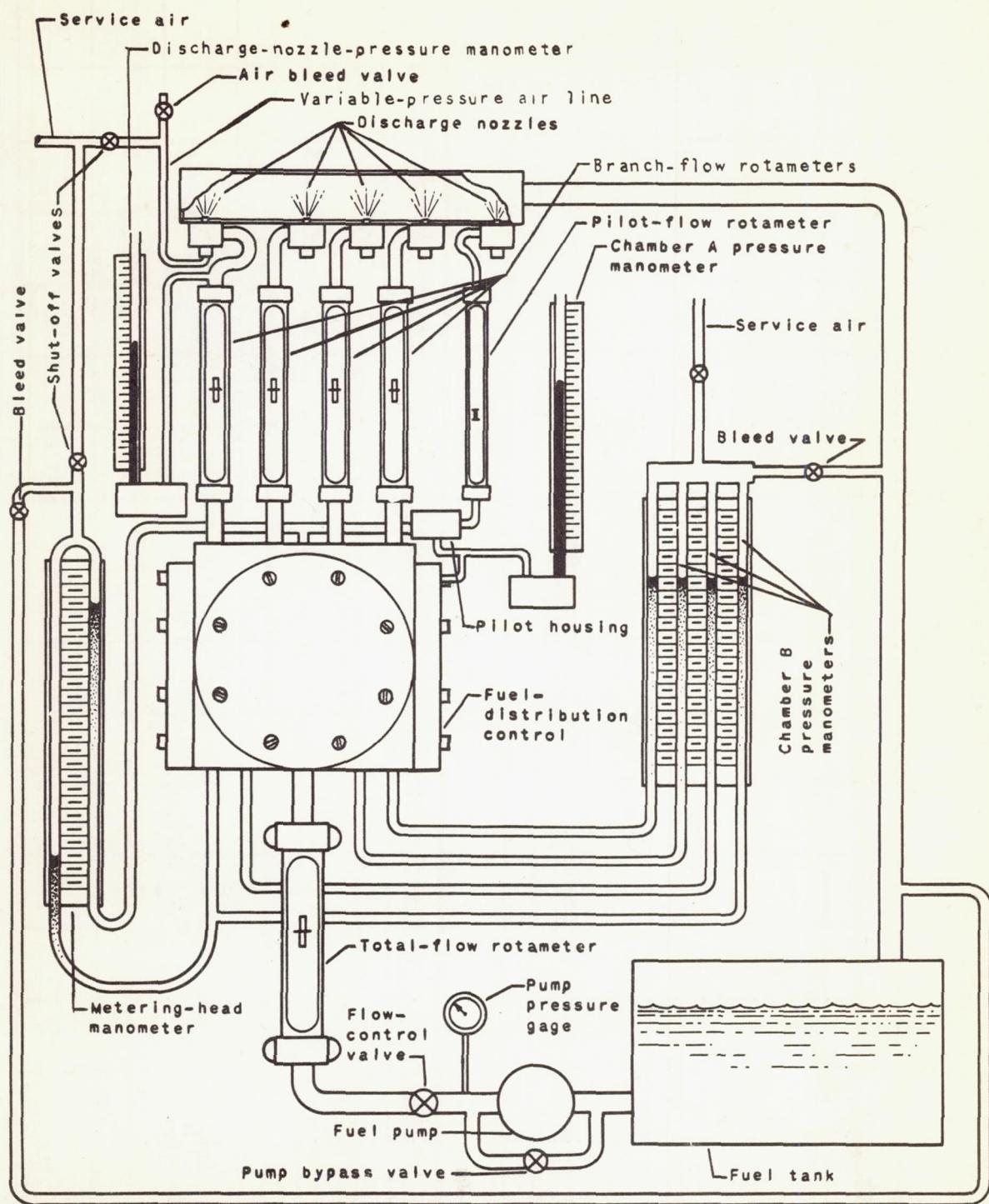


Figure 4. - Variation of fuel flow with metering head for matched metering jets used in experimental model of fuel-distribution control. Fuel specific gravity, 0.74 at 70° F.



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Figure 5. — Schematic diagram of apparatus with experimental model of fuel-distribution control.

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Fig. 6

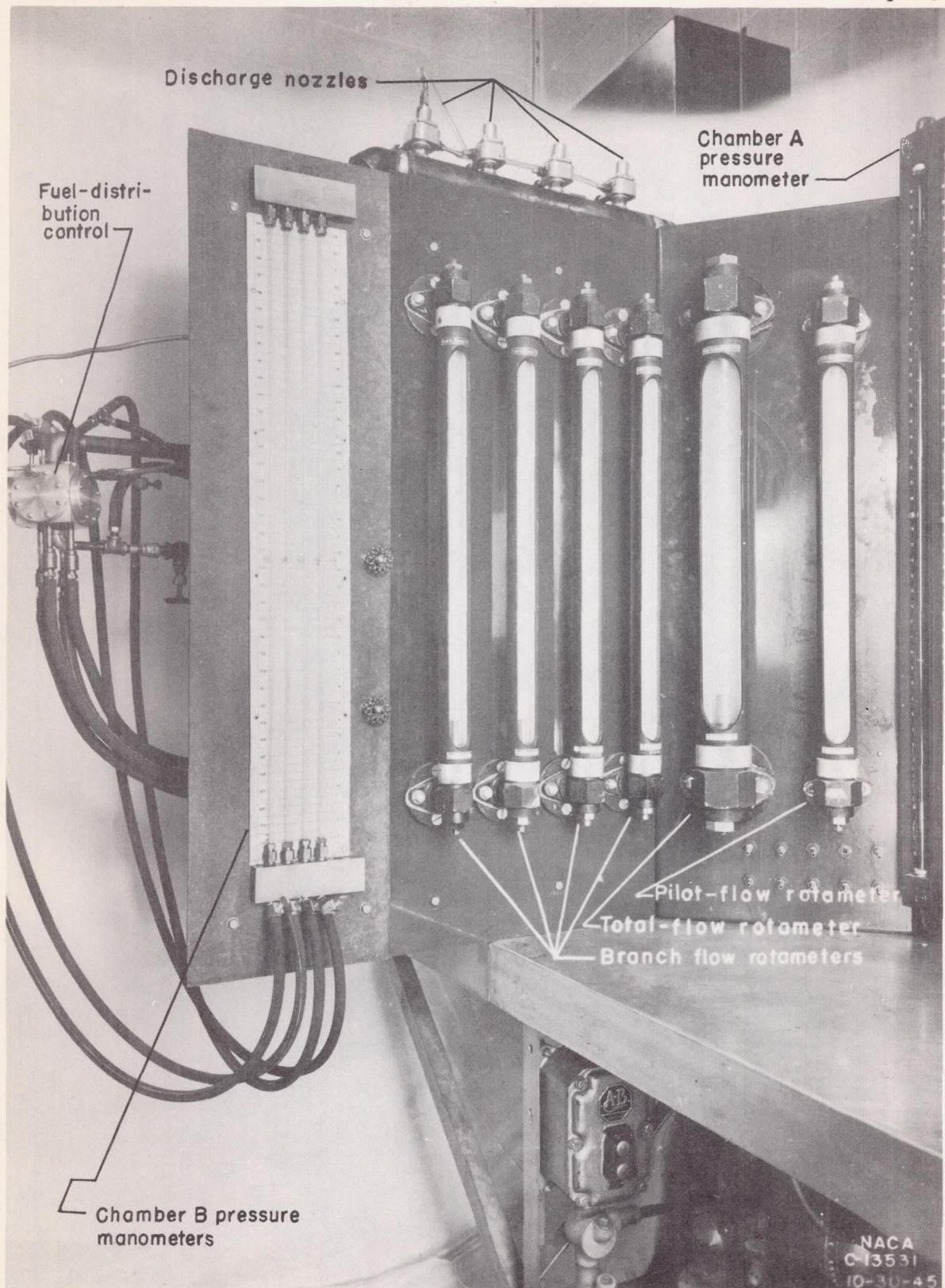


Figure 6. - Photograph of apparatus used with experimental model of fuel-distribution control.



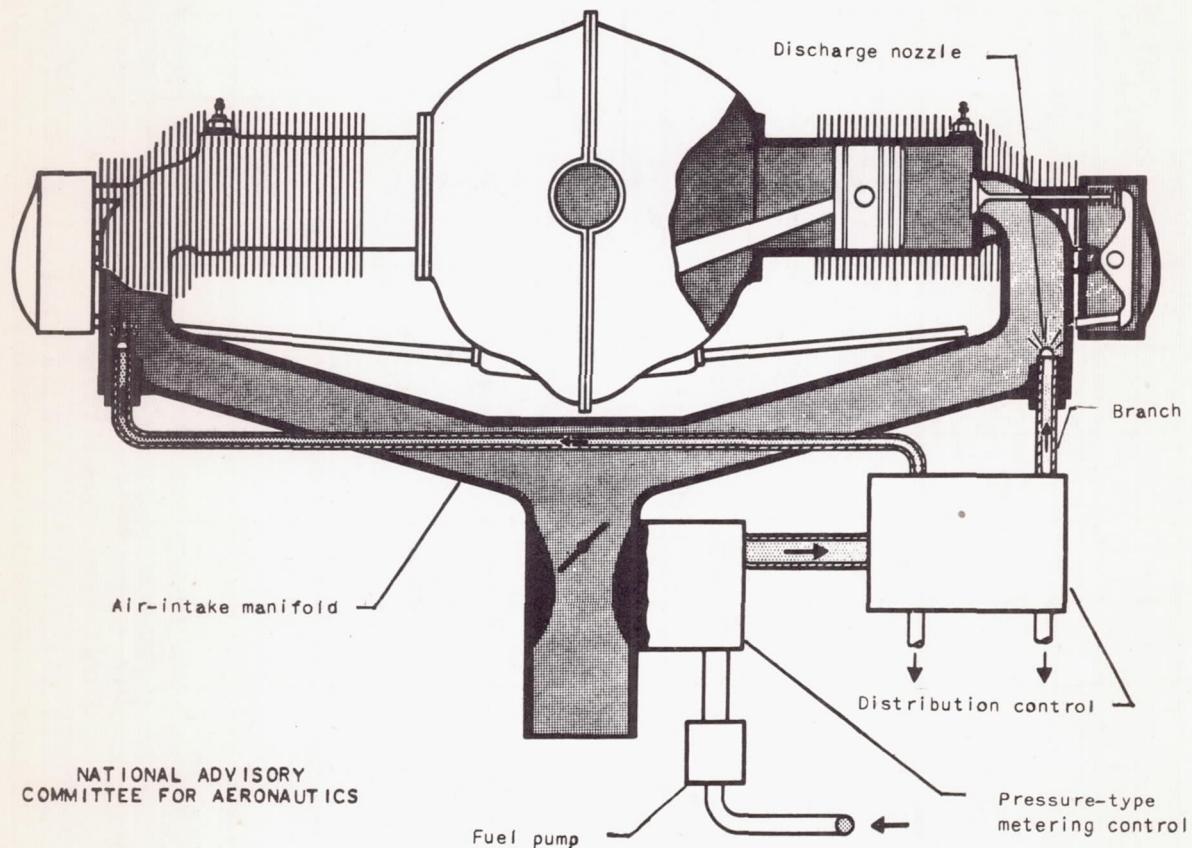


Figure 7. - Schematic diagram showing suggested method of installation of fuel-distribution control on reciprocating engine.

Fig. 8

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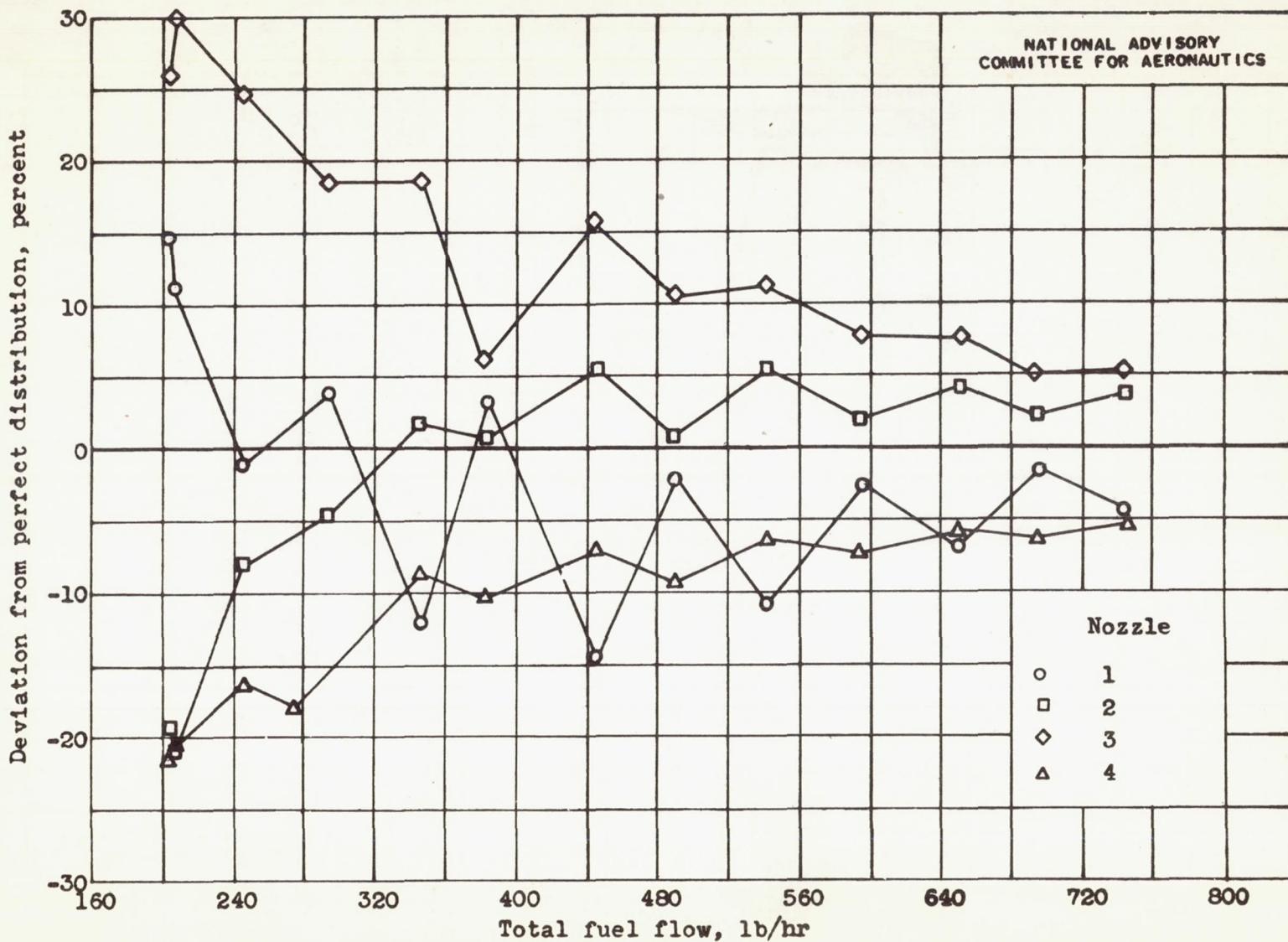


Figure 8. - Deviation from perfect distribution at various fuel flows of spring-loaded nozzles connected to manifold.

Deviation from perfect distribution, percent

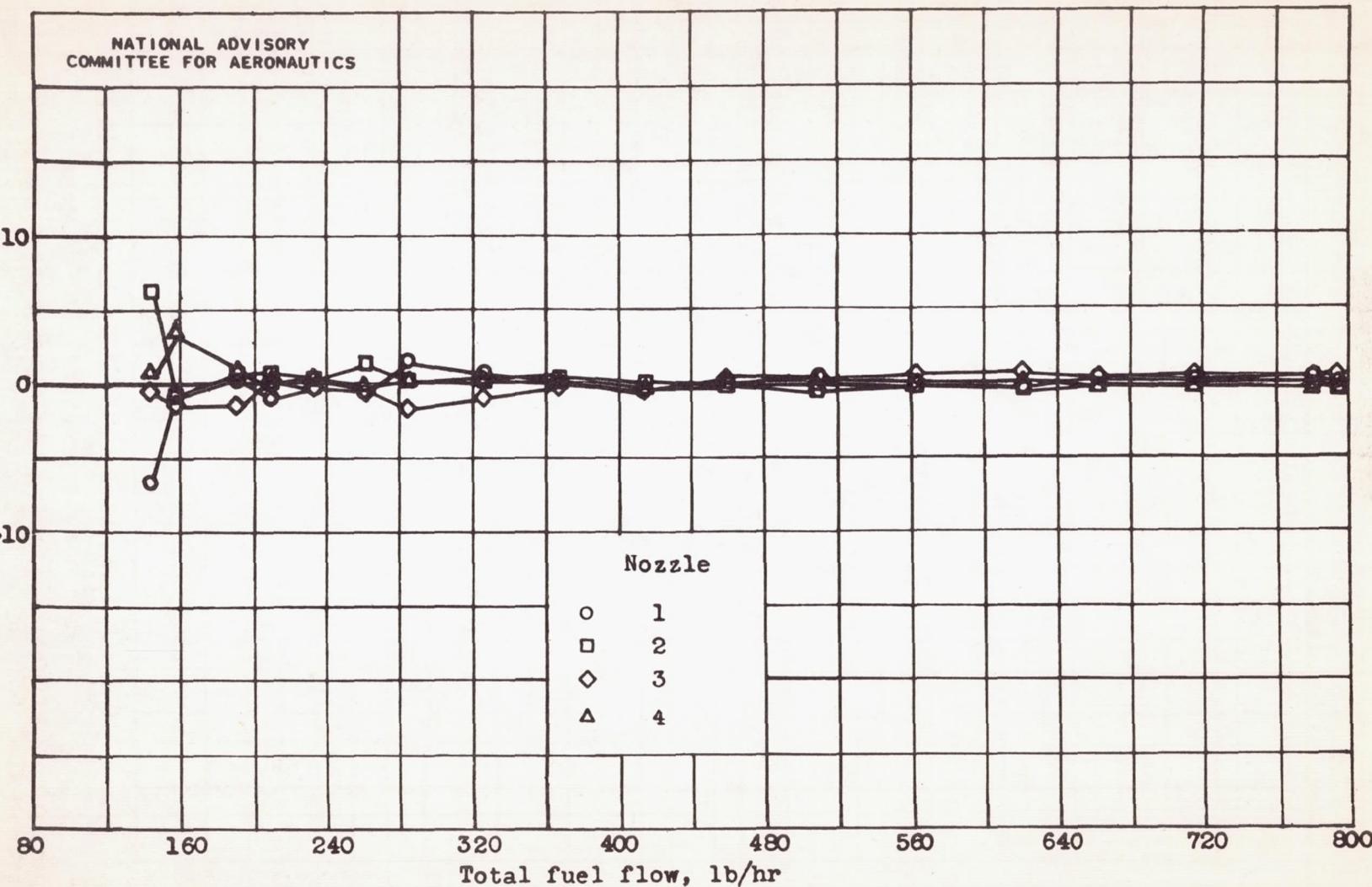


Figure 9. - Deviation from perfect distribution at various fuel flows of spring-loaded nozzles connected to experimental model of fuel-distribution control.

Fig. 10

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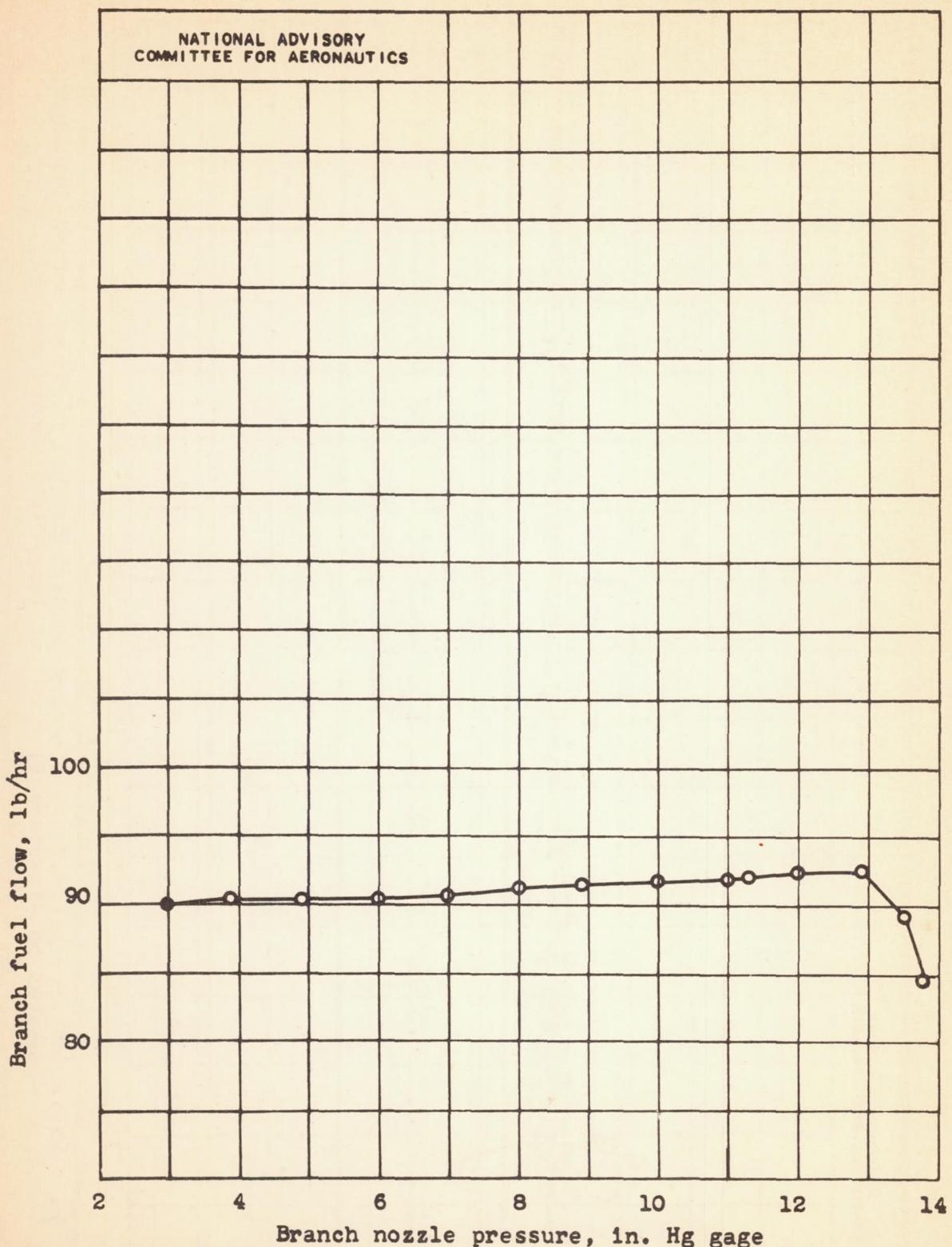


Figure 10. - Effect of varying discharge-nozzle pressure on branch fuel flow of experimental model of fuel-distribution control. Three discharge nozzles held at 11.3 inches of mercury gage; total fuel flow, 370 pounds per hour.